

## Calibrating a Field-level, Systems Dynamics Model of Terrorism's Human Capital Subsystem: GSPC as Case Study<sup>[1]</sup>

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### Introduction

The impetus for field-level inquiry into terrorism has been discussed elsewhere,<sup>[2]</sup> as has the current trend toward combining conceptual/theoretical, empirical and computational approaches for exploring the phenomenon.<sup>[3]</sup> Despite this trend, however, the number of published studies that combine systematically gathered, empirical data on a specific terrorist group with theoretically-grounded computational models is small,<sup>[4]</sup> although such work is clearly making important contributions in our knowledge and thinking about the phenomenon. Within work on terrorism, computational models derived from graph theory and social network analysis have begun to dominate the discourse,<sup>[5]</sup> but agent-based models of organizational information processes<sup>[6]</sup> and systems dynamics models<sup>[7]</sup> have also emerged. This paper seeks to offer an example of how systems dynamics can be used to describe one aspect of the terrorism field—specifically, terrorism's human capital subsystem. We also share insights gleaned from systematically calibrating the model to eight years' worth of data.

### Background

For model calibration, we collated data on the Salafist Group for Preaching and Combat (the *Groupe Salafiste pour la Prédication et le Combat*, or GSPC), designated as a foreign terrorist organization by the U.S. Government.<sup>[8]</sup> The group is active primarily in west and north Africa, with logistical networks within western Europe and a hazy relationship with al Qaeda.<sup>[9]</sup> GSPC emanated out of the Algerian civil war, breaking from the Armed Islamic Group (GIA, or *Groupe Islamique Arme*) under the leadership of Hassan Hattab in a purported dispute over group strategy and tactics.<sup>[10]</sup> Membership dwindled during the Civil Concord period (see [Appendix](#)).

GSPC's desired role in more contemporary Algerian politics is somewhat ambiguous. Reports suggest that Hattab, disillusioned with al Qaeda's influence on the group, left in 2001 and rejoined GSPC in 2003 while supporting government initiatives toward demilitarization.<sup>[11]</sup> Yet GSPC's de facto leader, Nabil Sahrawi, publicly announced GSPC support for al Qaeda in 2003,<sup>[12]</sup> and in 2006, numerous reports suggest GSPC is merging with al Qaeda.<sup>[13]</sup> Thus GSPC may be at another precipice of strategic transformation, and the conflicting reports may suggest a schism similar to that when Hattab's followers broke with GIA in 1998.

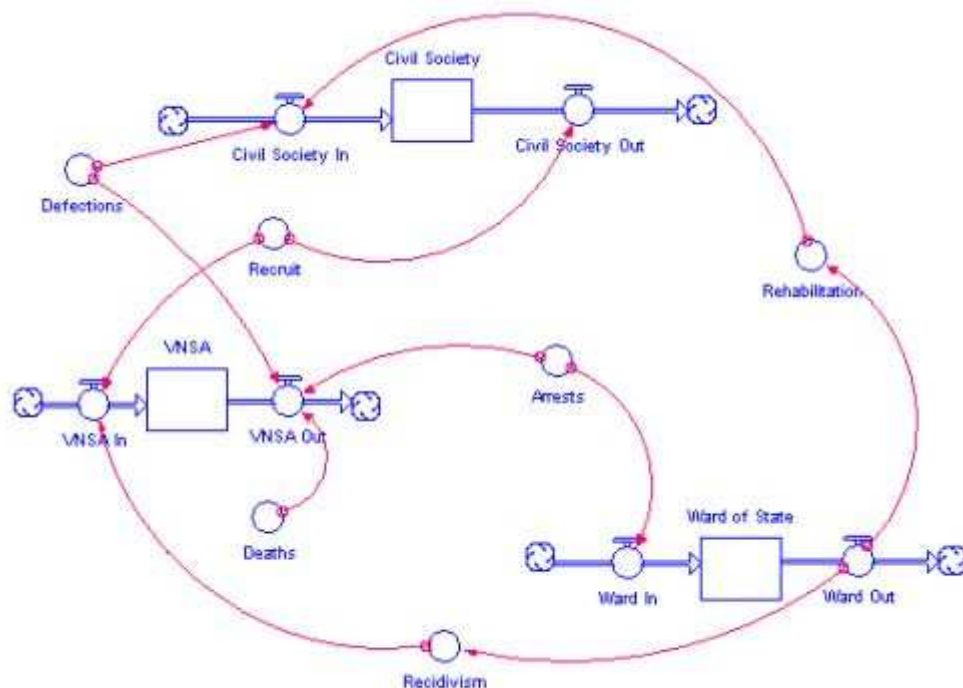
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## Model

The baseline descriptive model consists of three stocks and six flows of the terrorism field.[14] Building upon Bartolemei et al's work,[15] our model focuses primarily on the flow of personnel through a terrorist organization, rather than the recruitment of personnel to the organization. This modification elevates our investigation from an organizational to a field level[16] perspective of terrorism's human capital subsystem.

The stocks represent the three states that a nominal agent could assume within the model—civil society, violent non-state actor (VNSA), or ward of the state—while the six flows represent the processes through which a nominal agent could alter his or her state—recruit (join), arrest, death, defect, rehabilitation or recidivism. Civil society consists of all members of the population that are not wards of the state (e.g., under arrest or incarcerated) or members of the VNSA. Excepting the initial stock of VNSA members, a nominal agent would join the VNSA through the recruit process and could leave the VNSA through arrest by state personnel, being killed in a terrorist operation or state counterterrorist action, or defect back to civil society. If a member of the VNSA is arrested and becomes a ward of the state, two options are available: 1) rejoin civil society through the rehabilitation process, or 2) rejoin the VNSA through the recidivism process. The model is illustrated in [Figure 1](#).

**Figure 1 : Human Capital Flows through the Terrorism Field[17]**



Within the model, civil society stock decreases when one of its members is recruited into the VNSA, and increases when a VNSA member defects or a ward of the state rehabilitates. VNSA stock decreases when one of its members is arrested, killed or defects, and increases when a member of civil society is recruited or a ward of the state recedes. Ward of the state stock decreases as wards rehabilitate or recede, and the stock increases as VNSA members are arrested (see [Table 1](#)). We have also provided a notional, prescriptive counterterrorism goal and desired outcome for each stock as example of how the descriptive model could be linked to a prescriptive counterterrorism policy.

**Table 1: Stocks, flows and notional desired outcome[18]**

Stock	Processes for Decreasing	Processes for Increasing	Counterterrorism goal	Desired outcome
<b>Civil society</b>	Recruit	Defection	Maximize	Increase defection and rehabilitation
	Death	Rehabilitation		Decrease recruitment
<b>VNSA</b>	Arrest	Recruit Recidivism	Minimize	Decrease recruitment, recidivism, and deaths
	Death			Increase arrests and defection
	Defect			
<b>Ward of state</b>	Rehabilitation	Arrest	Obviate	Increase rehabilitation
	Recidivism			Decrease arrest and recidivism

Although our model is descriptive in nature, it easily could be tailored to various causal explanations, as the key flows—recruit, arrest, death, defect, rehabilitation or recidivism—can be expanded into subsystems into which causal explanations are embedded or even compared, and systems dynamics allows for interdependencies to be created between each. The aim is not to predict the exact stocks and flows of the model at a future time  $t + i$ , but rather to provide policymakers and other researchers with a means for exploring dynamic effects of counterterrorism actions.

### Existing Information Flows

A primary design aesthetic for the model was the ability for counterterrorism analysts and operates to easily incorporate *existing* information stores about the terrorism field under scrutiny. We posit that although such information may not be readily available, states generally have access to representative data, or at least expert estimates, of the number of recruits joining a VNSA during a given period and the number of VNSA members killed or arrested during the same. We also posit that states can estimate the level of defection, rehabilitation and recidivism associated with terrorist organizations in any given period. As a result, our model attempts to describe part of the human capital subsystem of the terrorism field (specifically, the portion of the human capital subsystem and joins and departs a VNSA) based on data readily accessible to state counterterrorism analysts and policy makers. The model is also easily extended to incorporate, and more ideally, compare and contrast, various causal explanations associated with each of the flows, such as the factors that increase arrests or decrease recruitment.

### Data Collection

Model calibration was based on data available on the Salafist Group for Preaching and Combat (GSPC) in Algeria from 1998 to second quarter 2006.

We reviewed several databases concerning information on the Armed Islamic Group (GIA) and its offshoot, the Salafist Group for Preaching and Combat (GSPC). Several well-known databases on terrorism yielded little useful data relative to our model,[19] as the information contained therein generally referenced successful attacks by terrorist groups, not information related more explicitly to counter- or

anti- terrorism measures, successes, and results. However, a service that translates foreign press proved to be profitable for the desired information. Data sources for the news service included Internet and print media in translations from Arabic and French.

Articles provided by the translated news service yielded a rich information store on activities related to the GIA and GSPC's human capital subsystems. Over 3,658 articles referencing the two groups from January 1, 1998 to June 2, 2006 were available for query. Our retrieval then narrowed to 618 translated news articles reflecting personnel flow through the VNSA: 1) group members killed in counterterrorism operations, internal conflicts (infighting), and retaliatory actions by intended victims; 2) group members arrested during counterterrorism operations; and 3) group members that surrendered due to amnesty programs or, assumedly, exhaustion and/or a sudden rise in conscience. In addition, the translated news articles also yielded some data points on recidivism (arrested or previously repentant terrorists that returned to the group). Little information was available, however, on recruitment into either group. Our assessment of information available within the database is captured in [Table 2](#).

**Table 2: Availability of Desired Information via Translated News Service**

Activity (during given quarter)	Availability of information via translated news service
Number of group members arrested	High
Number of group members killed	High
Number of group members surrendering/defecting	Medium
Number of new recruits	Low
Number of those arrested/surrendered/defected who rejoin group	Low
Number of those arrested/surrendered/defected who rejoin civil society	Low

## Coding

Data was coded into an Excel spreadsheet, extracting the following data and metadata from each article:

- Source identifier
- Source
- Article date
- Event year
- Event month
- Event date
- Group
- Recidivism
- Arrest
- Killed
- Arrest/killed reason
- Defections
- Defection reason
- Notes

Coding also adhered to the following guidelines for consistency.

1. All translated news articles referencing “GIA” or “GSPC” during the period of study were reviewed if the title or lead of the article indicated it contained data within the above categories. Data was classified as reflective of GIA, GSPC, or GIA-Hattab activities. Algeria and terrorism experts generally recognize GSPC as a splinter group of the GIA, founded during 1998 under the leadership of Hassan Hattab.<sup>[20]</sup> Actions related to Hattab’s organization were coded as GIA-Hattab until 1999, when the GSPC self-declared autonomy.<sup>[21]</sup>
2. Data recorded included only counterterrorism operations against known terrorists, usually referred to as “fighters” in the original reporting. Data collected does not include statistics referring to support networks. The distinction was made between those that engage in offensive, violent operations and extortions (e.g. assassinations, bombings, and road blocks) and those that limit their activities of a logistical nature (e.g. providing safe houses, money laundering, courier activities, and other general non-violent support).
3. Articles that did not reference specific numbers of group members affected by the counterterrorism action (e.g., Algerian officials indicate that ‘a few’ GSPC members were arrested on Sunday) were excluded. If a range of numbers was offered (25-28 arrested), the lower estimate was used.
4. As with any content analysis of foreign news, obvious translation errors and some ambiguity did occur; in nearly all cases, however, a critical reading for context tended to resolve ambiguous statements. For example, the term *element* often referred to and meant a single group member. The term *eliminated* was often used and was assumed to mean killed, while the term *neutralized* was assumed to mean arrested.
5. To be coded under recidivism, the article was required to use language specifically referencing previous membership in a terrorist group. Recruits from a “civilian” status were not coded.
6. Focus countries for activities were limited to the African continent: Algeria (DZA), Mauritania (MRT), Mali (MLI), Niger (NER), and Chad (TCD). European arrests, which were not insignificant, were not included due to the fact that the GSPC and GIA European diaspora have not shown violent tendencies but are often used as supporting elements for funding, recruitment, safe haven, and other related activities.
7. The reason for defection was generally coded as either 1) surrender or 2) amnesty. In the period under study, the Algerian government initiated two different amnesty periods: 1) Civil Concord from September 1999 to 13 January 2000<sup>[22]</sup> and 2) the Peace and National Reconciliation Charter from 29 September 2005 to July 2006.<sup>[23]</sup>
8. Several articles included multiple unique events over multiple time periods or geographically discontinuous *wilayas*. Each event was coded separately in the database, which resulted in some articles being coded for two or more events. However, each event, as entered in the database, was unique—if the same event was reported in two news sources, the more detailed account was used for coding and the other was annotated in the notes column.
9. Assessing total group membership was challenging due to sparse, vague, or geographically narrow data. As a result, various scholarly and U.S. government sources were used for data triangulation.<sup>[24]</sup> When data sources referred to “several,” several was generally assumed to equal a factor of three (e.g., several hundred = 300). In effect, this meant that if a source indicated that the GSPC consisted of “several hundred” members, we coded the total membership field with 300 and annotated the precise language in our notes.

10. Nearly all data used in this study was derived from a database of translated news reports, to include print and Internet media sources. Generally speaking, information on recruitment, overall membership and the action (rejoin, defect) of arrested and incarcerated members was lacking. Information on overall membership was augmented by other sources, including U.S. Department of State reports and scholarly articles. Further areas of data collection could include: expanding the database beyond the creation of the GSPC to include the creation of the GIA during the 1991-1992 timeframe, including the support networks, and specifically analyzing the nature of counterterrorism operations in Europe by Algerian terrorist groups.

Data was aggregated into monthly and quarterly sums for statistical comparison, and in some cases, the probability of VNSA members being arrested, killed or defecting was calculated based on available total membership information (See [Appendix](#)). In some cases, these probabilities were then incorporated into the model for calibration and “what if” analyses.

## Initial Hypothesis Testing

Despite the relative simplicity of our model, the opportunity to test a number of interesting hypotheses emerged as we sought to calibrate the systems dynamics model using our empirically-derived data set. We describe the testing of these hypotheses relative to the GSPC case study in this section.

### *Dependence and Collinearity of Defections, Arrests, and Kills of VNSA Members Due to Counterterrorism Actions*

Some observers of terrorist organizations might suggest that counterterrorism actions resulting in the arrest or death of current VNSA members would induce other VNSA members to defect from the organization or deter members of civil society from joining. While our data did not permit testing of the latter hypothesis, we were able to test the dependency of defections from the group as related to the arrest or death of group members.

#### *>> Hypothesis 1: The number of defections of GSPC member is influenced by the number of arrests or deaths of GSPC members.*

Generally speaking, this hypothesis was not supported, suggesting that ***an increase in the number of arrests or deaths of GSPC members had little to no influence on the defections of GSPC members back into civil society.*** This finding is important for our basic systems dynamics model, as it allows us to consider defections as a variable that is unaffected by, i.e., independent of, arrests and deaths due to counterterrorism actions. Thus, there is no requirement to introduce dependencies between either defections and arrests or defections and deaths in our model. Results are summarized in [Table 5](#).

### *Impact of Information Sharing Agreements*

The year 2002 serves as an intuitive point at which to partition the available data, as a significant number of environmental and organizational changes occurred. Most notably, the U.S. Pan-Sahel Initiative to train military and law enforcement forces in near countries (Mauritania, Mali, Niger and Chad) in counterterrorism operations started some time in fiscal year 2002.<sup>[25]</sup> Although it remains unclear if the United States provided similar counterterrorism training to Algerian military and security forces,<sup>[26]</sup> U.S. State Department reports indicate that the United States and Algeria enhanced counterterrorism information sharing efforts starting in late 2001.<sup>[27]</sup> This cooperation did not extend, however, to the provision of military equipment to Algeria.<sup>[28]</sup> Further, some observers of Algerian terrorism suggest that increased government counterterrorism actions, particularly coercive efforts, reduced GSPC's size toward its current estimated size of 300-500 active personnel. It was important, then, to determine whether the defections remained independent of arrests or deaths of GSPC members if the data were partitioned.



>> **Hypothesis 2: Between 1998-2001 or 2002-2006 Quarter 2, the number of GSPC defections is influenced by the arrest or death of GSPC members.**

This hypothesis was not supported, suggesting that **the number of GSPC defections is not influenced by the number of arrests or deaths of GSPC members under conditions of limited or enhanced foreign information sharing assistance to Algeria**. The statistical summary is incorporated into [Table 5](#).

Our data suggested an interesting finding that deserves mention—specifically, that likelihood of arrest or death of a GSPC member seemed to increase significantly starting in 2002, while the likelihood of defection decreased (see [Table 3](#)). Note the average probability of arrest increased ten-fold, the average probability of death doubled, and the average probability of defection halved when comparing these two periods.

**Table 3: Comparison of GSPC Member Arrest, Death or Defection: 1998-2001 vs. 2002-2006 Q2**

	1998 – 2001 (n = 16)				2002 – 2006 Q2 (n = 18)			
	Avg	Std Dev	Min	Max	Avg	Std Dev	Min	Max
<b>Aggregate</b>								
Arrest	<b>3.38</b>	6.48	0	22	<b>17.11</b>	17.04	0	71
Death	45.25	36.27	0	119	41.89	23.73	8	116
Defection	19.69	39.09	0	133	11.17	24.67	0	98
<b>Probability</b>								
Arrest	<b>0.0050</b>	0.0078	0	0.020	<b>0.056</b>	0.057	0	0.24
Death	0.068	0.064	0	0.27	0.13	0.076	0.027	0.39
Defection	<b>0.073</b>	0.18	0	0.67	<b>0.037</b>	0.082	0	0.33

These results led directly to the next hypothesis.

>> **Hypothesis 3: The arrest, death or defection of GSPC members increased in early 2002 as foreign-Algerian information sharing on counterterrorism increased.**

This hypothesis was partially supported. A binary dummy variable (foreign CT information sharing present = 1, foreign CT information sharing not present = 0) was created to assess whether the presence of foreign CT information sharing explained the change in the number or probability of arrests, defections, or deaths between the two periods. The analysis suggests that **the presence of foreign counterterrorism information sharing has a positive relationship between the aggregate number of arrests, the probability of GSPC member death, and the probability of GSPC member arrest during the period 1998 to second quarter 2006**. Results are included in [Table 5](#). As a note of caution, however, any number of causal variables could be attributed for influencing the number of arrests starting in 2002. Therefore, while our results are notable, the explanatory power of the presence of enhanced foreign information-sharing relationships is weak at best. Nonetheless, the arrest data clearly behaves differently during these two periods; the causes and meaning of this difference warrants further investigation

### **Collinearity of VNSA Members Being Arrested or Killed during Counterterrorism Actions**

Counterterrorism operations that result in the kill or arrest of VNSA members rest on the coercive end of the coercive-cooptive power spectrum of anti- and counterterrorism action. Given the coercive nature of these events and the risk that attempts to arrest VNSA members could lead to exchanges of violence between the terrorist group and security forces, we expected strong collinearity between arrests and kills, leading to the next hypothesis.



>> **Hypothesis 4: The arrests and deaths of GSPC members due to counterterrorism operations exhibit a strong interdependency.**

This hypothesis was not supported, suggesting that **arrests and deaths of GSPC members do not exhibit strong collinearity**, even when compared using two and three quarter moving averages. As a result of this analysis, we are fairly confident in retaining representations in our model that allow for the independence of defections, arrests, and deaths of VNSA members due to counterterrorism operations.

### Amnesties

Many governments have employed amnesties in order to encourage defection from terrorist groups, including Italy, Algeria, and Great Britain. Amnesties would be included among in the class of creative government policies for counterterrorism[29] and have demonstrated effectiveness in a variety of contexts.[30] Anecdotal evidence suggests that terrorist organization members with less ideological commitment to 1) violent action and 2) the group's selection of tactics and targets could be swayed to leave the group if the punishment for having joined initially would be reduced and/or others are also encouraged to leave.[31] This evidence intuitively leads to hypothesizing that GSPC defections will increase during the presence of an amnesty.

>> **Hypothesis 5: During amnesty periods, the number of defections and the probability of defection relative to total GSPC membership increases.**

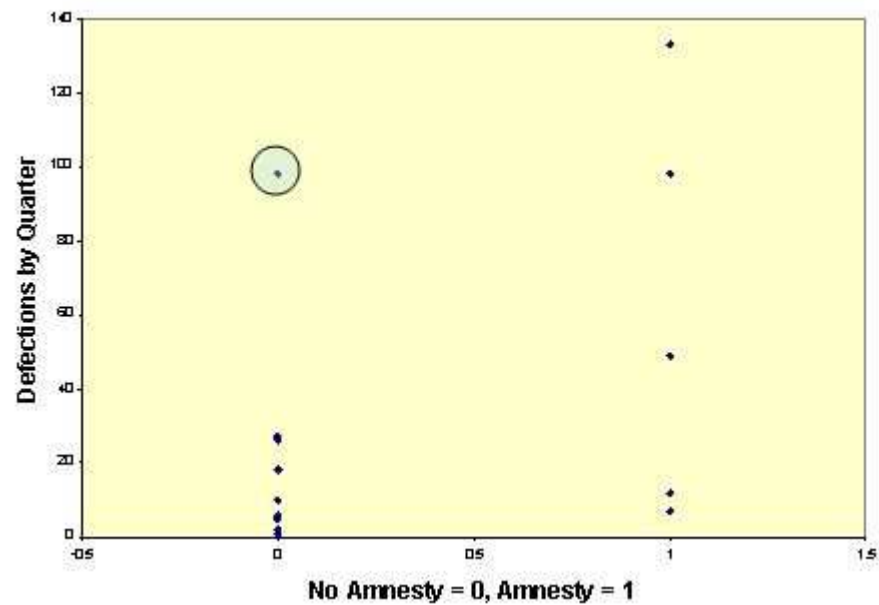
Our data suggests this hypothesis is supported. To test it, we created a binary dummy variable ( $x=0$  if no amnesty was in effect,  $x=1$  if an amnesty was in effect for the given period). Results of the linear regressions are incorporated into [Table 5](#). As one might expect, *there exists a **relatively strong positive correlation between the implementation of an amnesty period and the number of defections from GSPC reported in local press***. Our calculations suggest that *on average, GSPC defections increased by 19.3 members per month and 44.8 members per quarter during amnesty periods. Using the probabilities as derived in the [Appendix](#), this translates into the probability of defections increased by 0.20 during amnesty periods*. Whether this finding is a function of the attention space of our data source (local press) or an artifact of how amnesties and their environmental associates affect terrorist organizations requires further research. [Table 4](#) provides detail.

**Table 4: Correlation between Amnesty Period and Defections**

		<i>m</i>	<i>b</i>	$R^2$	F	<i>Df</i>	P	N
# of Defections by Month	Amnesty Present	21.6	2.33	0.16	18.9	99	<0.001	101
# of Defections by Quarter	Amnesty Present	52.3	7.48	0.34	16.8	32	<0.001	34
P(Defections) by Quarter	Amnesty Present	0.22	0.021	0.35	16.4	32	<0.001	34

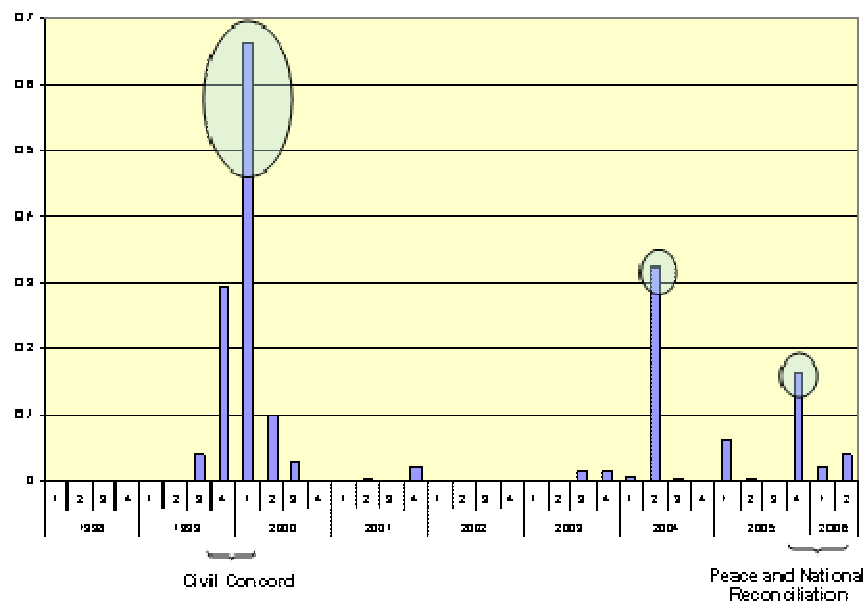
However, as the  $R^2$  values indicate, defections do not occur solely during amnesty periods, nor is a significant increase in defections present during all quarters in which a government amnesty is present.

**Figure 2: Number of GSPC Defections per Quarter vs. Presence of Amnesty**



Examining the data more closely, we note that defections significantly increased in second quarter 2004, despite lack of a declared amnesty by the Algerian government. This finding requires more investigation that is beyond the scope of this paper.

**Figure 3: Probability of GSPC Defections by Quarter**



[Table 5](#) summarizes results of the regressions.

**Table 5: Coefficient of Determination for Selected Constructs**

Correlations for Selected Constructs ( $R^2, N$ )							
		6	7	8	9	11	12
1	# Defections	0.02 34	0.01 34			0.018 34	0.16* 101 0.34* 34
2	# Defections, 3 mo delay	<0.01 33	0.04 33				
3	# Defections, 6 mo delay	0.06 32	0.01 32				
4	# Defections, 1998-2001			0.00 16	0.04 16		
5	# Defections, 2002-June 2006			0.03 18	0.01 18		
6	# Arrests		<0.0001 34			0.22** 34	<0.003 34
7	# Deaths					0.0033 34	
8	P(Defection)					0.61 34	0.35* 34
9	P(Arrest)					0.29** 34	
10	P(Death)					0.15*** 34	
11	Presence of foreign information sharing						
12	Presence of amnesty						
* $p<0.001$ , ** $p<0.005$ , *** $p<0.01$ , **** $p<0.05$ . Quarterly aggregations were used excepting $N=101$ , representing monthly aggregations.							

## Calibration: Univariate Models

Using empirical data, we calibrated the basic descriptive model by parsimoniously manipulating variables and then building on previous manipulations. Our goal was to replicate the expected values of total GSPC membership over the 34 quarters for which our data were available. Total membership figures for VNSA are often elusive,[32] and the GSPC is no exception. However, we were able to approximate GSPC membership through collating data from various sources, and then extrapolating total membership for those quarters in which data was missing. Details of our estimations are available in [Appendix](#). Goodness of fit between membership data predicted by our model manipulations and the estimated total membership data was assessed through calculating root mean square errors ( $RMSE$ ) and Nash and Sutcliffe Coefficient of Efficiency ( $E$ ).[33] Predicted value is considered a better “fit” to observed data as  $RMSE$  tends toward 0 and  $E$  tends toward 1, with  $0 \leq RMSE < \infty$  and  $-\infty < E \leq 1$ .

## >> Model A: Empirical Averages

For our first model (A), inputs represented empirically-derived averages for the arrests, deaths and defections of GSPC members—i.e., at each  $\Delta t$ , 10.65 VNSA members were arrested and became Wards, 43.37 were killed, and 15.18 defected back to Civil Society. As expected, by holding recruitment, recidivism and rehabilitation at zero, the VNSA as modeled was unable to regenerate personnel strength

after losses to defections, arrests and deaths. However, this model is quite unrealistic, and as expected, both *RMSE* and *E* were quite high.

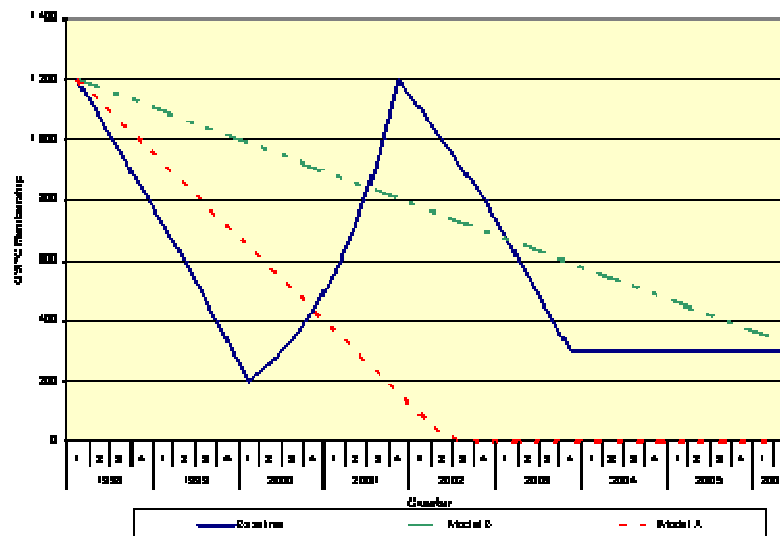
### >> Model B: Incorporating the Recruitment Estimation Technique

Our second model (B) allowed the VNSA to recruit members from Civil Society in order to replenish its stock based on the average obtained through the following simple formula, which provides rudimentary technique for estimating recruitment to the VNSA:

$$\text{Recruits} = \begin{cases} \frac{1}{n} \sum_{i=1}^n \text{TotalMembers}_i - (\text{TotalMembers}_{i-1} - \text{Arrest}_i - \text{Death}_i - \text{Defect}_i) & \text{if } > 0 \\ 0 & \text{else} \end{cases} \quad \text{Eq. (1)}$$

*RMSE* and *E* were quite improved with this model (B), with *RMSE* and *E* greatly improved over a number of more detailed and subsequent models. This finding suggests that incorporation of even a rudimentary recruitment estimate (in our case, a one for one replacement of losses suffered by the group due to arrests, deaths, and defections during that quarter) greatly enhances model fidelity. Moreover, we suggest that when terrorist organizations are declining due to loss of membership to arrests, deaths, or defects, simultaneously applying counterterrorism measures that limit or stymie recruitment could prove beneficial. Results are illustrated in [Figure 4](#).

**Figure 4: Baseline vs. Model A and B Predictions**



### >> Model C: Presence of Amnesty Program

Our third model (C) represented a first attempt at introducing a causal variable into the model—i.e., the presence of an amnesty program. Defections were modeled as 59.8 per quarter if an amnesty was present (the empirical average of defections during the Civil Concord and Peace and National Reconciliation Period) and 7.48 per quarter if an amnesty was not present, while arrests and deaths were modeled at the empirical averages for the entire reporting period. With this model, *RMSE* and *E* were less desirable than the basic empirical averages with (Model B) and without (Model A) use of the Recruitment Estimation Technique. Models C<sub>1-4</sub> further partitioned the data into amnesty and non-amnesty periods;

model fidelity was significantly enhanced over Model C's use of averages over the entire period for arrests, deaths, and recruitment.

### >> *Model D: Representing Amnesty Programs Uniquely*

Our fourth model (D) proceeded similarly to Model C, except we disaggregated our amnesty-related data between the Civil Concord period (Sep 1999 to Jan 2000) and the Peace and National Reconciliation period. *RMSE* and *E* improved over all previous models. Notably, however, Models D<sub>1-4</sub> did not behave similarly to models C<sub>1-4</sub>. Specifically, model C<sub>4</sub> suggested that if we calibrated all data elements within the model according to the presence or non-presence of amnesty periods, goodness of fit would improve. Yet in Model D<sub>3</sub>, calibrating all data elements within the model according to *unique* amnesty programs actually *worsened* goodness of fit. This finding indicates that the two amnesty periods may have created significantly different effects across GSPC's human capital subsystem. Indeed, [Figure 3](#) suggests that probability of defection reached a high of 0.6 during the Civil Concord period, but only 0.2 during the Peace and National Reconciliation period. Although the results are preliminary, we suggest that while the presence of amnesties may be universally beneficial for increasing defections from a terrorist organization, each amnesty exhibits unique systemic effects due to the changing interplay of contextual factors over time. This finding appears consistent with Cronin's suggestion that while historical case studies can suggest the types of counterterrorism policies that accompany the decline or end of terrorist organizations, applying similar policies in more contemporary contexts may result in similar, but not exactly duplicated, results.[\[34\]](#)

### >> *Model E: Foreign Information Sharing Relationships*

The Algerian government's access to enhanced information sharing relationships with foreign powers started roughly in approximately early 2002.[\[35\]](#) Our data and hypothesis testing suggested that these information sharing agreements resulted in statistically significant correlations with the number and probability of GSPC arrests reported in the open press, so we partitioned elements of our data set according to presence or absence of the enhanced information sharing relationships. Surprisingly, goodness of fit was reduced, suggesting that this variable (presence of enhanced foreign information sharing relationship) was not as significant as the previously modeled variable (presence of an amnesty program) in terms of its overarching effects across the human capital subsystem.

Specifics of calibrations for Models A-E are provided in [Table 6](#). Our baseline model—empirical averages supplemented by our Recruitment Estimation Technique (Model B)—is highlighted in yellow. Improvements in goodness of fit achieved through model calibration are highlighted in light green (light gray); models with significant reduced goodness of fit are highlighted in peach (dark gray).



**Table 6: Model Calibrations—Univariate System Drivers**

Model	Arrests	Deaths	Defections	Recruitment	RMSE	E	N
A	10.65	43.37	15.18	0	480.57	1.39	34
B	10.65	43.37	15.18	42.82	337.98	0.18	34
C	10.65	43.37	$\begin{cases} 598 \text{ Arrests/Recruitment} \\ 748 \text{ Arrests/Deaths} \end{cases}$	42.82	361.26	0.35	34
C <sub>1</sub>	10.65	$\begin{cases} 2860 \text{ Arrests/Recruitment} \\ 4605 \text{ Arrests/Deaths} \end{cases}$	15.18	42.82	332.35	0.14	34
C <sub>2</sub>	$\begin{cases} 1240 \text{ Arrests/Recruitment} \\ 1258 \text{ Arrests/Deaths} \end{cases}$	43.37	15.18	42.82	328.03	0.11	34
C <sub>3</sub>	10.65	43.37	15.18	$\begin{cases} 4740 \text{ Arrests/Recruitment} \\ 4203 \text{ Arrests/Deaths} \end{cases}$	336.70	0.17	34
C <sub>4</sub>	$\begin{cases} 1240 \text{ Arrests/Recruitment} \\ 1258 \text{ Arrests/Deaths} \end{cases}$	$\begin{cases} 2860 \text{ Arrests/Recruitment} \\ 4605 \text{ Arrests/Deaths} \end{cases}$	$\begin{cases} 598 \text{ Arrests/Recruitment} \\ 748 \text{ Arrests/Deaths} \end{cases}$	$\begin{cases} 4740 \text{ Arrests/Recruitment} \\ 4203 \text{ Arrests/Deaths} \end{cases}$	336.46	0.17	34
D	10.65	43.37	$\begin{cases} 1153 \text{ Civil/Concord} \\ 2267 \text{ Peace/Conciliation} \\ 748 \text{ Else} \end{cases}$	42.82	331.44	0.14	34
D <sub>1</sub>	10.65	$\begin{cases} 235 \text{ Civil/Concord} \\ 32 \text{ Peace/Conciliation} \\ 5990 \text{ Else} \end{cases}$	15.18	42.82	342.62	0.21	34
D <sub>2</sub>	$\begin{cases} 2 \text{ Civil/Concord} \\ 1933 \text{ Peace/Conciliation} \\ 1069 \text{ Else} \end{cases}$	43.37	15.18	42.82	343.61	0.22	34
D <sub>3</sub>	10.65	43.37	15.18	$\begin{cases} 75 \text{ Civil/Concord} \\ 74 \text{ Peace/Conciliation} \\ 4203 \text{ Else} \end{cases}$	320.72	0.06	34
D <sub>4</sub>	$\begin{cases} 2 \text{ Civil/Concord} \\ 1933 \text{ Peace/Conciliation} \\ 1069 \text{ Else} \end{cases}$	$\begin{cases} 235 \text{ Civil/Concord} \\ 32 \text{ Peace/Conciliation} \\ 5990 \text{ Else} \end{cases}$	$\begin{cases} 1153 \text{ Civil/Concord} \\ 2267 \text{ Peace/Conciliation} \\ 748 \text{ Else} \end{cases}$	$\begin{cases} 75 \text{ Civil/Concord} \\ 74 \text{ Peace/Conciliation} \\ 4203 \text{ Else} \end{cases}$	377.86	0.48	34
E	10.65	43.37	$\begin{cases} 1969 \text{ 1998-2001} \\ 1117 \text{ 2002-present} \end{cases}$	42.82	326.27	0.10	34
E <sub>1</sub>	10.65	$\begin{cases} 4523 \text{ 1998-2001} \\ 4189 \text{ 2002-present} \end{cases}$	15.18	42.82	332.63	0.14	34
E <sub>2</sub>	$\begin{cases} 338 \text{ 1998-2001} \\ 1711 \text{ 2002-present} \end{cases}$	43.37	15.18	42.82	338.55	0.18	34
E <sub>3</sub>	10.65	43.37	15.18	$\begin{cases} 6831 \text{ 1998-2001} \\ 2017 \text{ 2002-present} \end{cases}$	466.14	1.25	34
E <sub>4</sub>	$\begin{cases} 338 \text{ 1998-2001} \\ 1711 \text{ 2002-present} \end{cases}$	43.37	$\begin{cases} 1969 \text{ 1998-2001} \\ 1117 \text{ 2002-present} \end{cases}$	42.82	348.00	0.25	34
E <sub>5</sub>	$\begin{cases} 338 \text{ 1998-2001} \\ 1711 \text{ 2002-present} \end{cases}$	$\begin{cases} 4525 \text{ 1998-2001} \\ 4189 \text{ 2002-present} \end{cases}$	$\begin{cases} 1969 \text{ 1998-2001} \\ 1117 \text{ 2002-present} \end{cases}$	$\begin{cases} 6831 \text{ 1998-2001} \\ 2017 \text{ 2002-present} \end{cases}$	471.29	1.30	34

## Discussion

Incorporating our rudimentary Recruitment Estimation Technique (RET) significantly improved goodness of fit with the empirically collated data. More interestingly, however, the behavior of the system when the univariate system drivers were applied to a singular flow (e.g., arrests OR defections OR deaths OR recruitment) of the system vs. the behavior of the system when the univariate system driver was applied across the human capital subsystem's entirety (e.g., arrests AND defections AND deaths AND recruitment) were quite different. As Models C<sub>4</sub>, D<sub>4</sub>, and E<sub>5</sub> reveal, applying the same univariate system driver across *all* the flows within the terrorism field actually *degraded* the model's fidelity by reducing goodness of fit. However, applying a univariate system driver to a singular flow often improved goodness of fit.

Improvements in goodness of fit associated with incorporating the RET suggests that when researchers model dynamic subsystems such as the flow of terrorism's human capital, they must consider not only outflows (e.g., arrests, deaths, defections) but also inflows (e.g., recidivism, recruitment) in order to adequately capture the dynamicism of the system study—a rather obvious observation to the seasoned modeler

This degradation occurred primarily when higher fidelity data was applied across all flows within the system—e.g., when the presence of a particular amnesty, for example, was modeled as a system driver for the field's entire human capital subsystem. The degradation was also acutely noticeable when foreign information-sharing was applied as a causal explanation for variance in recruitment data. [Table 7](#) captures the change in the Nash-Sutcliffe coefficient of efficiency ( $E$ ) for model flows and causal explanations. The matrix suggests that *misattributing* causal explanations to flows within the human capital subsystem can significantly degrade a model's utility, a degradation that provides less accurate results than using simple empirical averages. This finding leads us to suggest that for some analytical purposes, use of empirical averages may be sufficient for exploring the basic dynamics of terrorism's many subsystems. We also note, however, that the model improved most when the following relationships were introduced:

- Arrest data varied with presence or absence of amnesty
- Recruitment data varied with presence or absence of a *unique* amnesty
- Defections data varied with presence or absence of foreign information-sharing, presence or absence of amnesty, and presence or absence of a *unique* amnesty

**Table 7: Change in  $E$  from Baseline—Human Capital Flows vs. Causal Explanations**

Goodness of Fit	Flow	Possible Causal Explanation		
		Amnesty	Unique Amnesty	Foreign Info Sharing
Improvement	Arrests	+0.07		
	Deaths	+0.03		+0.04
	Defections	+0.04	+0.04	+0.08
	Recruitment	+0.01	+0.12	
	All	+0.01		
Degradation	Arrests		-0.04	0.00
	Deaths		-0.03	
	Defections			
	Recruitment			-1.07
	All		-0.30	-1.12

In short, analysts building systems-level terrorism models must be acutely mindful to avoid incorporating causal relationships that are empirically untested into their representations. Modelers of the terrorism field may thus wish to err on the side of limiting, rather than enlarging, the number of causal relationships incorporated into their models. Thus for the terrorism systems modeler, parsimony might be interpreted as incorporating only those causal relationships that are theoretically tenable (so the relationships can be tested), empirically justified, or some combination of the two approaches.

### Calibration: Allowing for Dominant Subsystem Drivers

As the univariate models (Models C-E) and our regressions ([Table 5](#)) suggest, some personnel flows with terrorism's human capital subsystem appear to be dominated by specific subsystem drivers. Yet modeling a singular causal variable across the entire human capital subsystem provides inaccurate model predictions. Further, lack of correlation among arrests, defections, and deaths over the period under study suggested that the set of system drivers for each flow within the subsystem might be unique. For example, since our regression analyses suggested that the presence of enhanced information sharing relationships with foreign powers affected arrests—but not deaths or defections of GSPC members—we intuited that calibration of arrests should be tied to the presence or absence of information sharing relationships.



Based on our regressions using presence of amnesty as a dummy variable and Models C and D, however, we intuited that defections should be calibrated according to the presence of unique amnesty programs. These intuitions required checking against available empirical evidence, and model calibrations proceeded as outlined in [Table 8](#). Models with improved goodness of fit over the baseline averages (Model B) are highlighted in green (light gray); models with degraded goodness of fit over the baseline averages are highlighted in peach (dark gray).

**Table 8: Model Calibrations—Multivariate System Drivers**

Model	Arrests	Deaths	Defections	Recruitment	RMSE	E	N
F	$\begin{bmatrix} 1240 \text{ Amnesty granted} \\ 1258 \text{ Amnesty absent} \end{bmatrix}$	$\begin{bmatrix} 4525 \text{ 1998-2001} \\ 4189 \text{ 2002-present} \end{bmatrix}$	$\begin{bmatrix} 1969 \text{ 1998-2001} \\ 1117 \text{ 2002-present} \end{bmatrix}$	$\begin{bmatrix} 75 \text{ Civil Concord} \\ 74 \text{ Peace/Reconciliation} \\ 4203 \text{ Else} \end{bmatrix}$	315.56	-0.03	34
G	$\begin{bmatrix} 1718 \text{ 1998-2001} \\ 1711 \text{ 2002-present} \end{bmatrix}$	$\begin{bmatrix} 4525 \text{ 1998-2001} \\ 4189 \text{ 2002-present} \end{bmatrix}$	$\begin{bmatrix} 1969 \text{ 1998-2001} \\ 1117 \text{ 2002-present} \end{bmatrix}$	$\begin{bmatrix} 75 \text{ Civil Concord} \\ 74 \text{ Peace/Reconciliation} \\ 4203 \text{ Else} \end{bmatrix}$	322.06	-0.07	34
N	$\begin{bmatrix} 338 \text{ 1998-2001} \\ 1711 \text{ 2002-present} \end{bmatrix}$	$\begin{bmatrix} 4525 \text{ 1998-2001} \\ 4189 \text{ 2002-present} \end{bmatrix}$	$\begin{bmatrix} 1155 \text{ Civil Concord} \\ 2267 \text{ Peace/Reconciliation} \\ 748 \text{ Else} \end{bmatrix}$	$\begin{bmatrix} 75 \text{ Civil Concord} \\ 74 \text{ Peace/Reconciliation} \\ 4203 \text{ Else} \end{bmatrix}$	328.29	-0.11	34
M	$\begin{bmatrix} 338 \text{ 1998-2001} \\ 1711 \text{ 2002-present} \end{bmatrix}$	43.37	$\begin{bmatrix} 1155 \text{ Civil Concord} \\ 2267 \text{ Peace/Reconciliation} \\ 748 \text{ Else} \end{bmatrix}$	$\begin{bmatrix} 75 \text{ Civil Concord} \\ 74 \text{ Peace/Reconciliation} \\ 4203 \text{ Else} \end{bmatrix}$	331.48	-0.14	34
O	$\begin{bmatrix} 338 \text{ 1998-2001} \\ 1711 \text{ 2002-present} \end{bmatrix}$	$\begin{bmatrix} 235 \text{ Civil Concord} \\ 32 \text{ Peace/Reconciliation} \\ 5990 \text{ Else} \end{bmatrix}$	$\begin{bmatrix} 1155 \text{ Civil Concord} \\ 2267 \text{ Peace/Reconciliation} \\ 748 \text{ Else} \end{bmatrix}$	$\begin{bmatrix} 75 \text{ Civil Concord} \\ 74 \text{ Peace/Reconciliation} \\ 4203 \text{ Else} \end{bmatrix}$	363.87	-0.37	34
I	$\begin{bmatrix} 338 \text{ 1998-2001} \\ 1711 \text{ 2002-present} \end{bmatrix}$	$\begin{bmatrix} 4525 \text{ 1998-2001} \\ 4189 \text{ 2002-present} \end{bmatrix}$	$\begin{bmatrix} 598 \text{ Amnesty granted} \\ 748 \text{ Amnesty absent} \end{bmatrix}$	42.82	383.22	-0.52	34
K	$\begin{bmatrix} 338 \text{ 1998-2001} \\ 1711 \text{ 2002-present} \end{bmatrix}$	43.37	$\begin{bmatrix} 598 \text{ Amnesty granted} \\ 748 \text{ Amnesty absent} \end{bmatrix}$	$\begin{bmatrix} 4740 \text{ Amnesty granted} \\ 4203 \text{ Amnesty absent} \end{bmatrix}$	389.28	-0.57	34
J	$\begin{bmatrix} 338 \text{ 1998-2001} \\ 1711 \text{ 2002-present} \end{bmatrix}$	43.37	$\begin{bmatrix} 598 \text{ Amnesty granted} \\ 748 \text{ Amnesty absent} \end{bmatrix}$	42.82	392.35	-0.59	34
L	$\begin{bmatrix} 338 \text{ 1998-2001} \\ 1711 \text{ 2002-present} \end{bmatrix}$	$\begin{bmatrix} 4525 \text{ 1998-2001} \\ 4189 \text{ 2002-present} \end{bmatrix}$	$\begin{bmatrix} 1155 \text{ Civil Concord} \\ 2267 \text{ Peace/Reconciliation} \\ 748 \text{ Else} \end{bmatrix}$	$\begin{bmatrix} 6831 \text{ 1998-2001} \\ 2017 \text{ 2002-present} \end{bmatrix}$	465.72	-1.24	34
H	$\begin{bmatrix} 338 \text{ 1998-2001} \\ 1711 \text{ 2002-present} \end{bmatrix}$	$\begin{bmatrix} 4525 \text{ 1998-2001} \\ 4189 \text{ 2002-present} \end{bmatrix}$	$\begin{bmatrix} 598 \text{ Amnesty granted} \\ 748 \text{ Amnesty absent} \end{bmatrix}$	$\begin{bmatrix} 6831 \text{ 1998-2001} \\ 2017 \text{ 2002-present} \end{bmatrix}$	530.24	-1.90	34

## Discussion

As [Table 8](#) lists, Models F, G, M and N suggest that the most significant system driver for recruitment was the presence or absence of a specific amnesty period. While this finding could be self-fulfilling as a result of the formula derived for our Recruitment Estimation Technique (Eq. 1), the finding could also indicate that during amnesty periods, recruitment to the GSPC suffered significantly. More broadly, this finding could suggest that implementation of co-optive counterterrorism techniques[36] not only encourages defection from a terrorist organization, but also discourages recruits to a terrorist organization. Second, while deaths of alleged GSPC members certainly spiked during some quarters for which data was available (see [Appendix](#)), the model calibrations suggest that the presence of an amnesty program, the presence of enhanced information sharing with a foreign power, or even a more detailed longitudinal partitioning were not correlated with these spikes. At a minimum, a third causal explanation should be incorporated into the descriptive model to account for variability of deaths during different periods under study.

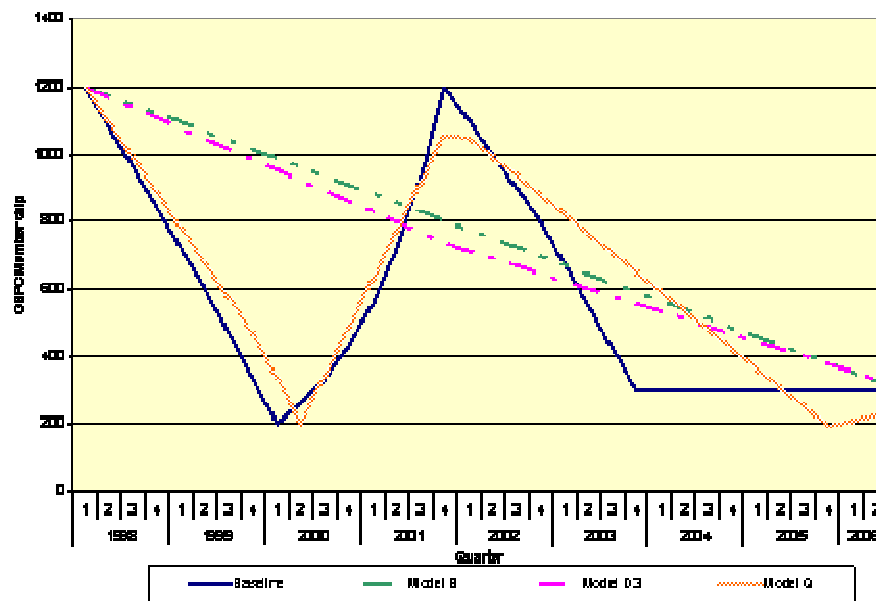
None of the model calibrations usurped the fit established in the simplistic Model B (i.e., empirical averages plus the Recruitment Estimation Technique) until two manipulations were modeled simultaneously: 1) a partition of the data into five major time periods: before Civil Concord, during Civil Concord, after Civil Concord but before 2002, after 2001 but before Peace and National Reconciliation, and during Peace and National Reconciliation; and 2) derived recruitment values, when negative, were added to the defection values.[37] These two simultaneous manipulations are represented in Model R.

**Table 9: Model Calibrations—Time-Partitioned System Drivers**

Model	Arrests	Deaths	Defections	Recruitment	RMSE	E	N
P	$\begin{cases} 0.19 P_{t-1} +_{\text{Constant}} \\ - 0.01 P_{t-2} +_{\text{Constant}} - 2001 \\ 16673602 - P_{t-1} +_{\text{Constant}} \\ 19.11 P_{t-1} +_{\text{Constant}} \end{cases}$	$\begin{cases} 0.41 P_{t-1} +_{\text{Constant}} \\ 0.12 P_{t-2} +_{\text{Constant}} \\ - 0.01 P_{t-3} +_{\text{Constant}} - 2001 \\ 41273601 - P_{t-1} +_{\text{Constant}} \\ - 11 P_{t-1} +_{\text{Constant}} \end{cases}$	$\begin{cases} 0.19 P_{t-1} +_{\text{Constant}} \\ 0.12 P_{t-2} +_{\text{Constant}} \\ - 0.01 P_{t-3} +_{\text{Constant}} - 2001 \\ 41273601 - P_{t-1} +_{\text{Constant}} \\ - 11 P_{t-1} +_{\text{Constant}} \end{cases}$	$\begin{cases} 0.19 P_{t-1} +_{\text{Constant}} \\ 0.12 P_{t-2} +_{\text{Constant}} \\ - 0.01 P_{t-3} +_{\text{Constant}} - 2001 \\ 41273601 - P_{t-1} +_{\text{Constant}} \\ - 11 P_{t-1} +_{\text{Constant}} \end{cases}$	468.80	-1.47	34
Q	$\begin{cases} 0.19 P_{t-1} +_{\text{Constant}} \\ - 0.01 P_{t-2} +_{\text{Constant}} - 2001 \\ 16673602 - P_{t-1} +_{\text{Constant}} \\ 19.11 P_{t-1} +_{\text{Constant}} \end{cases}$	$\begin{cases} 0.41 P_{t-1} +_{\text{Constant}} \\ 0.12 P_{t-2} +_{\text{Constant}} \\ - 0.01 P_{t-3} +_{\text{Constant}} - 2001 \\ 41273601 - P_{t-1} +_{\text{Constant}} \\ - 11 P_{t-1} +_{\text{Constant}} \end{cases}$	$\begin{cases} 0.19 P_{t-1} +_{\text{Constant}} \\ 0.12 P_{t-2} +_{\text{Constant}} \\ - 0.01 P_{t-3} +_{\text{Constant}} - 2001 \\ 41273601 - P_{t-1} +_{\text{Constant}} \\ - 11 P_{t-1} +_{\text{Constant}} \end{cases}$	$\begin{cases} 0.19 P_{t-1} +_{\text{Constant}} \\ 0.12 P_{t-2} +_{\text{Constant}} \\ - 0.01 P_{t-3} +_{\text{Constant}} - 2001 \\ 41273601 - P_{t-1} +_{\text{Constant}} \\ - 11 P_{t-1} +_{\text{Constant}} \end{cases}$	132.16	0.82	34

In total, fit of the model calibrations varied widely (i.e.,  $-1.90 \leq E \leq 0.82$ ,  $132.16 \leq RMSE \leq 539.29$ ), but Models D3, F, G and Q provided the best fits. Predictions are illustrated in [Figure 5](#) and compared against the baseline empirical data.

**Figure 5: Baseline vs. Selected Model Predictions**



## Conclusion

This work demonstrates how our baseline, descriptive model of stocks and flows within terrorism's human capital subsystem might be calibrated to a specific group of interest using 1) translated news reports as the primary data source and 2) two basic causal explanations as subsystem drivers. We are encouraged by the goodness of fit with the empirical baseline data, which suggests that our basic model may be of utility for terrorism researchers working with data sources of rudimentary granularity, especially if a Recruitment Estimation Technique (RET) is incorporated. Further, while our demonstration was based on publicly accessible data, we expect that state agents may have access to data with even greater granularity than used in this demonstration, and we are encouraged that by following our basic framework, the model might be calibrated using those agents' existing information stores.

As the baseline membership and our calibrations suggest, future modelers of GSPC may wish to demarcate GSPC into four separate periods: prior to, during and following the civil concord period, and then from 2002 to the present. Specifically, the average number of arrests, defections, and deaths per quarter varied significantly between these four periods. Reports that GSPC is joining with al Qaeda may also suggest the need for a new demarcation point for any models calibrated using GSPC data from mid-2006 and beyond, with joining al Qaeda representing a significant revamping of GSPC's strategy.

At an overarching level, our regressions and calibrations lead us to our primary conclusion: that for terrorist organizations, the presence or absence of an amnesty program is an important system driver across the human capital enterprise. This finding is, of course, not new. Anecdotal evidence has often suggested that amnesties are effective when states seek to encourage members of violent non-state organizations toward non-violent means. However, many assertions of the effectiveness of amnesty programs have not been subjected to rigorous, systematic data collation and regression analysis. Our nascent work in this area perhaps provides an initial methodology for exploring the role of amnesties toward inducing violent groups toward non-violent action; hopefully, future research can improve upon this methodology. Further, our systematic collation of defection data and correlation of this data to Algerian amnesty periods indicates that Algeria's two major amnesty periods created similar, but unique, effects across the system—GSPC defections were higher during the Civil Concord period in 1999-2000 than in the later Peace and National Reconciliation period starting in late 2005. These differences suggest that contextual factors play an important role in the effectiveness of amnesty programs. The divergence opens yet another window for exploring how organizational contingency theory applies to terrorist groups, and in particular, for exploring how organizational contingency theory might assist counterterrorism policymakers in efforts to weaken the proclivity toward violent strategies and tactics by non-state actors.

## About the Authors

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## Appendix: GSPC Members Defecting, Being Arrested, or Being Killed (by Quarter)

Table 10: Quarterly Data of Arrests, Deaths, and Defections of GSPC Members

Year	Quarter	Arrested[38]	Killed[38]	Defected[38]	Membership[39]
1998	1	0	0	0	<b>1200[40]</b>
	2	0	101	0	1080
	3	0	91	0	960
	4	0	11	0	840
1999	1	0	19	0	720
	2	0	28	0	<b>600[41]</b>
	3	2	19	18	467
	4	4	23	98	433
2000	1	0	24	133	<b>200[42]</b>
	2	6	95	26	258
	3	0	42	10	334
	4	4	38	0	431[43]
2001	1	0	119	1	557
	2	0	20	2	719
	3	22	41	0	929
	4	16	53	27	<b>1200[44]</b>
2002	1	2	64	0	1100
	2	0	49	1	1000
	3	20	54	0	900
	4	25	19	0	<b>800[45]</b>
2003	1	13	31	0	675
	2	11	41	1	550
	3	13	53	6	425
	4	71	47	5	<b>300[46]</b>
2004	1	16	116	2	300[47]
	2	1	38	98	300
	3	9	42	1	300
	4	3	17	0	<b>300[48]</b>
2005	1	1	15	18	300
	2	30	36	1	<b>300[49]</b>
	3	35	36	0	<b>300[50]</b>
	4	26	41	49	<b>300[51][52]</b>
2006	1	19	8	7	<b>300[53][54]</b>
	2[55]	13	47	12	<b>300</b>

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1. The work contained herein is the sole responsibility of the authors and should not be construed as an official position or policy of the U.S. Government. Portions of this work were previously published as Leweling, Tara A., and Otto Sieber, "Using Systems Dynamics to Explore Effects of Counterterrorism Policy," *Proceedings of the Hawaii International Conference on Systems Science*, Hilton Waikoloa Village on the Big Island, Shidler College of Business, University of Hawai'i at Manoa, 3-6 Jan, 2007. We are indebted to Professor Thomas Johnson and three anonymous reviewers for their helpful insights on earlier drafts.
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